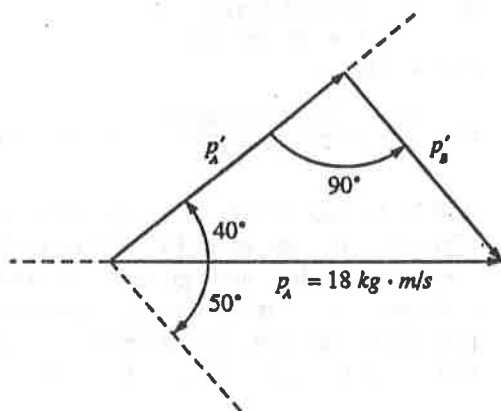


# Practice Problems

14. A 6.0-kg object, *A*, moving at velocity 3.0 m/s, collides with a 6.0-kg object, *B*, at rest. After the collision, *A* moves off in a direction  $40.0^\circ$  to the left of its original direction. *B* moves off in a direction  $50.0^\circ$  to the right of *A*'s original direction.

- a. Draw a vector diagram and determine the momenta of object *A* and object *B* after the collision.



$$p_A + p_B = p'_A + p'_B \text{ (vector sum)}$$

$$\text{with } p_B = 0$$

$$p_A = m_A v_A = (6.0 \text{ kg})(3.0 \text{ m/s}) = 18 \text{ kg} \cdot \text{m/s}$$

$$p'_A = p_A \cos 40^\circ = (18 \text{ kg} \cdot \text{m/s}) \cos 40^\circ$$

$$p'_A = p_A \sin 40^\circ = (18 \text{ kg} \cdot \text{m/s}) \sin 40^\circ$$

$$= 14 \text{ kg} \cdot \text{m/s}$$

$$p'_B = p_A \sin 40^\circ = (18 \text{ kg} \cdot \text{m/s}) \sin 40^\circ$$

$$= 12 \text{ kg} \cdot \text{m/s}$$

- b. What is the velocity of each object after the collision?

$$p'_A = m_A v'_A,$$

$$v'_A = \frac{p'_A}{m_A} = \frac{(14 \text{ kg} \cdot \text{m/s})}{(6.0 \text{ kg})}$$

$$= 2.3 \text{ m/s}, 40^\circ \text{ to left}$$

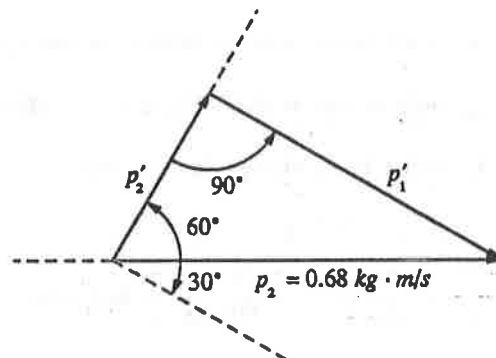
$$p'_B = m_B v'_B,$$

$$v'_B = \frac{p'_B}{m_B} = \frac{(12 \text{ kg} \cdot \text{m/s})}{(6.0 \text{ kg})}$$

$$= 2.0 \text{ m/s}, 50^\circ \text{ to right}$$

# Practice Problems

15. A stationary billiard ball of mass 0.17 kg is struck by a second, identical ball moving at 4.0 m/s. After the collision, the second ball moves off in a direction  $60^\circ$  to the left of its original direction. The stationary ball moves off in a direction  $30^\circ$  to the right of the second ball's original direction. What is the velocity of each ball after the collision?



$$p_1 + p_2 = p'_1 + p'_2 \text{ (vector sum) with } p_1 = 0$$

$$m_1 = m_2 = m = 0.17 \text{ kg}$$

$$p_2 = m_2 v_2 = (0.17 \text{ kg})(4.0 \text{ m/s}) = 0.68 \text{ kg} \cdot \text{m/s}$$

$$p'_1 = p_2 \sin 60^\circ, mv'_1 = mv_2 \sin 60^\circ,$$

$$v'_1 = v_2 \sin 60^\circ = (4.0 \text{ m/s}) \sin 60^\circ$$

$$= 3.5 \text{ m/s}, 30^\circ \text{ to right}$$

$$p'_2 = p_2 \cos 60^\circ, mv'_2 = mv_2 \cos 60^\circ,$$

$$v'_2 = v_2 \cos 60^\circ = (4.0 \text{ m/s}) \cos 60^\circ$$

$$= 2.0 \text{ m/s}, 60^\circ \text{ to left}$$

## Chapter Review Problems

1. Jenny has a mass of 35.6 kg and her skateboard has a mass of 1.3 kg. What is Jenny and her skateboard's momentum if they are going 9.50 m/s?

$$\text{Total mass is } 35.6 \text{ kg} + 1.3 \text{ kg} = 36.9 \text{ kg}$$

$$mv = (36.9 \text{ kg})(9.50 \text{ m/s}) = 351 \text{ kg} \cdot \text{m/s}$$

2. A hockey player makes a slap shot, exerting a force of 30.0 N on the hockey puck for 0.16 s. What impulse is given to the puck?

$$F\Delta t = (30.0 \text{ N})(0.16 \text{ s}) = 4.8 \text{ kg} \cdot \text{m/s}$$

3. The hockey puck shot in Problem 2 has a mass of 0.115 kg and was at rest before the shot. With what speed does it head toward the goal?

$$F\Delta t = m\Delta v, \text{ so } \Delta v = \frac{F\Delta t}{m} = \frac{4.8 \text{ kg m/s}}{0.115 \text{ kg}} \\ = 42 \text{ m/s}$$

4. A force of 6.00 N acts on a 3.00-kg object for 10.0 s.

- a. What is the object's change in momentum?

$$m\Delta v = F\Delta t = (6.00 \text{ N})(10.0 \text{ s}) = 60.0 \text{ N}\cdot\text{s}$$

- b. What is its change in velocity?

$$m\Delta v = F\Delta t, \text{ so}$$

$$\Delta v = \frac{F\Delta t}{m} = \frac{60.0 \text{ N}\cdot\text{s}}{3.00 \text{ kg}} = 20.0 \text{ m/s}$$

5. The velocity of a 600-kg auto is changed from +10.0 m/s to 44.0 m/s in 68.0 s by an applied, constant force.

- a. What change in momentum does the force produce?

$$\Delta p = m\Delta v \\ = (600 \text{ kg})(44.0 \text{ m/s} - 10.0 \text{ m/s}) \\ = 2.04 \times 10^4 \text{ N}\cdot\text{s}$$

- b. What is the magnitude of the force?

$$F\Delta t = m\Delta v, \text{ so}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{2.04 \times 10^4 \text{ N}\cdot\text{s}}{68.0 \text{ s}} = 300 \text{ N}$$

6. A 845-kg drag race car accelerates from rest to 100 km/h in 0.90 seconds.

- a. What is the change in momentum of the car?

$$m\Delta v = (845 \text{ kg}) \left[ \left( 100 \frac{\text{km}}{\text{h}} \right) \left( \frac{1000 \text{ m}}{1 \text{ km}} \right) \left( \frac{1 \text{ h}}{3600 \text{ s}} \right) - 0 \right] \\ = 2.35 \times 10^4 \text{ kg}\cdot\text{m/s}$$

- b. What average force is exerted on the car?

$$F\Delta t = m\Delta v, \text{ so}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{2.35 \times 10^4 \text{ kg}\cdot\text{m/s}}{0.90 \text{ s}} \\ = 2.6 \times 10^4 \text{ N}$$

7. A sprinter with a mass of 76 kg accelerates from 0 to 9.4 m/s in 2.8 s. Find the average force acting on the runner.

$$m\Delta v = (76 \text{ kg})(9.4 \text{ m/s} - 0)$$

$$= 7.1 \times 10^2 \text{ kg}\cdot\text{m/s}$$

$$F\Delta t = m\Delta v, \text{ so}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{7.1 \times 10^2 \text{ kg}\cdot\text{m/s}}{2.8 \text{ s}} = 2.6 \times 10^2 \text{ N}$$

8. A 0.25-kg soccer ball is rolling 6.0 m/s toward a player. The player kicks the ball back in the opposite direction and gives it a velocity of -14 m/s. What is the average force during the interaction between the player's foot and the ball if the interaction lasts  $2.0 \times 10^{-2}$  s?

$$F\Delta t = m\Delta v, \text{ so}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{(0.25 \text{ kg})[(-14 \text{ m/s}) - (6.0 \text{ m/s})]}{2.0 \times 10^{-2} \text{ s}}$$

$$= -2.5 \times 10^2 \text{ N}$$

9. A force of  $1.21 \times 10^3$  N is needed to bring a car moving at +22.0 m/s to a halt in 20.0 s? What is the mass of the car?

$$m\Delta v = F\Delta t, \text{ so}$$

$$m = \frac{F\Delta t}{\Delta v} = \frac{(-1.21 \times 10^3 \text{ N})(20.0 \text{ s})}{0 - 22.0 \text{ m/s}}$$

$$= 1.10 \times 10^3 \text{ kg}$$

10. Small rockets are used to make small adjustments in the speed of satellites. One such rocket has a thrust of 35 N. If it is fired to change the velocity of a 72 000-kg spacecraft by 63 cm/s, how long should it be fired?

$$F\Delta t = m\Delta v, \text{ so}$$

$$\Delta t = \frac{m\Delta v}{F} = \frac{(72 \text{ 000 kg})(0.63 \text{ m/s})}{35 \text{ N}}$$

$$= 1.3 \times 10^3 \text{ s}$$

or about 22 min

11. A 10 000-kg freight car is rolling along a track at 3.00 m/s. Calculate the time needed for a force of 1000 N to stop the car.

$$F\Delta t = m\Delta v, \text{ so } \Delta t = \frac{m\Delta v}{F}$$

$$\Delta v = v_f - v_i = 0 - 3.00 \text{ m/s and}$$

$F = -1000 \text{ N}$  (the negative sign is because it is a retarding force), therefore

$$\Delta t = \frac{(10\,000 \text{ kg})(-3.00 \text{ m/s})}{(-1000 \text{ N})} = 30.0 \text{ s}$$

12. A car moving at 10 m/s crashes into a barrier and stops in 0.25 m.

- a. Find the time required to stop the car.

$$d = \frac{1}{2}(v_i + v_f)t, \text{ so}$$

$$t = \frac{2d}{v_i + v_f} = \frac{2(0.25 \text{ m})}{0 + 10 \text{ m/s}} = 5.0 \times 10^{-2} \text{ s}$$

- b. If a 20-kg child were to be stopped in the same time as the car, what average force must be exerted?

$$F\Delta t = m\Delta v, \text{ so}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{(20 \text{ kg})(0 - 10 \text{ m/s})}{5.0 \times 10^{-2} \text{ s}}$$

$$= -4.0 \times 10^3 \text{ N}$$

- c. Approximately what is the mass of an object whose weight equals the force from part b? Could you lift such a mass with your arm?

$$W = mg, \text{ so}$$

$$m = \frac{W}{g} = \frac{4.0 \times 10^3 \text{ N}}{9.80 \text{ m/s}^2} = 4.1 \times 10^2 \text{ kg}$$

No.

- d. What does your answer to part c say about holding an infant on your lap instead of using a separate infant restraint?

Holding the child on your lap is dangerous to both the child and yourself.

13. An animal-rescue plane flying due east at 36.0 m/s drops a bale of hay from an altitude of 60.0 m. If the bale of hay weighs 175 N, what is the momentum of the bale the moment it strikes the ground?

First use projectile motion to find the velocity of the bale.

$$v_x = 36.0 \text{ m/s}$$

$$v_y^2 = v_{oy}^2 + 2dg, \text{ so}$$

$$v_y = \sqrt{2dg} = \sqrt{2(-60.0 \text{ m})(-9.80 \text{ m/s}^2)}$$

$$= \sqrt{1.18 \times 10^3 \text{ m}^2/\text{s}^2} = 34.3 \text{ m/s}$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(36.0 \text{ m/s})^2 + (34.3 \text{ m/s})^2}$$

$$= 49.7 \text{ m/s}$$

Now find the mass from  $w = mg$ , so

$$m = \frac{W}{g} = \frac{175 \text{ N}}{9.80 \text{ m/s}^2} = 17.9 \text{ kg}$$

$$mv = (17.9 \text{ kg})(49.7 \text{ m/s}) = 888 \text{ kg} \cdot \text{m/s}$$

Now the angle from the two velocities.

$$\tan \theta = \frac{v_y}{v_x} = \frac{34.3 \text{ m/s}}{36.0 \text{ m/s}}, \text{ so } \theta = 43.6^\circ$$

The momentum is 888 kg·m/s at 43.6° below horizontal.

14. A 10-kg lead brick falls from a height of 2.0 m.

- a. Find its momentum as it reaches the ground.

$$v_y^2 = v_{oy}^2 + 2gd, \text{ so}$$

$$v_y = \sqrt{2gd} = \sqrt{2(9.80 \text{ m/s}^2)(2.0 \text{ m})} = 6.3 \text{ m/s}$$

$$mv = (10 \text{ kg})(6.3 \text{ m/s}) = 63 \text{ kg} \cdot \text{m/s}$$

- b. What impulse is needed to bring the brick to rest?

$$F\Delta t = m\Delta v = 63 \text{ N} \cdot \text{s}$$

## Chapter Review Problems

- c. The brick falls onto a carpet, 1.0 cm thick. Assuming the force stopping it is constant, find the average force the carpet exerts on the brick.

$$d = \frac{1}{2}(v_t + v_i)t, \text{ so}$$

$$t = \frac{2d}{v_t + v_i} = \frac{2(0.010 \text{ m})}{0 + 6.3 \text{ m/s}} = 3.2 \times 10^{-3} \text{ s}$$

$$F\Delta t = m\Delta v, \text{ so}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{63 \text{ kg} \cdot \text{m/s}}{3.2 \times 10^{-3} \text{ s}} = 2.0 \times 10^4 \text{ N}$$

- d. If the brick falls onto a 5.0-cm foam rubber pad, what constant force is needed to bring it to rest?

$$t = \frac{2d}{v_t + v_i} = \frac{2(0.050 \text{ m})}{0 + 6.3 \text{ m/s}} = 1.6 \times 10^{-2} \text{ s}$$

$$F = \frac{m\Delta v}{\Delta t} = \frac{63 \text{ kg} \cdot \text{m/s}}{1.6 \times 10^{-2} \text{ s}} = 4.0 \times 10^3 \text{ N}$$

15. A 60-kg dancer leaps 0.32 m high.

- a. With what momentum does the dancer reach the ground?

$$v_t^2 = v_i^2 + 2gd, \text{ so}$$

$$v_t = \sqrt{2gd} = \sqrt{2(9.80 \text{ m/s}^2)(0.32 \text{ m})} = 2.5 \text{ m/s}$$

$$mv = (60 \text{ kg})(2.5 \text{ m/s}) = 1.5 \times 10^2 \text{ kg} \cdot \text{m/s}$$

- b. What impulse is needed to make a stop?

$$F\Delta t = m\Delta v = 1.5 \times 10^2 \text{ N} \cdot \text{s}$$

- c. As the dancer lands, the knees bend, lengthening the time required to stop to 0.050 s. Find the average force exerted on the body.

$$F\Delta t = 1.5 \times 10^2 \text{ N} \cdot \text{s}, \text{ so}$$

$$F = \frac{1.5 \times 10^2 \text{ N} \cdot \text{s}}{\Delta t} = \frac{1.5 \times 10^2 \text{ N} \cdot \text{s}}{0.050 \text{ s}} = 3.0 \times 10^3 \text{ N}$$

- d. Compare the stopping force to the performer's weight.

$$W = mg = (60 \text{ kg})(9.80 \text{ m/s}^2) = 5.9 \times 10^2 \text{ N}$$

or the force is about 5 times the weight.

## Chapter Review Problems

16. A 95-kg fullback running at 8.2 m/s collides in midair with a 128-kg defensive tackle moving in the opposite direction. Both players end up with zero speed.

- a. What was the fullback's momentum before the collision?

$$mv = (95 \text{ kg})(8.2 \text{ m/s}) = 7.8 \times 10^2 \text{ kg} \cdot \text{m/s}$$

- b. What was the change in the fullback's momentum?

$$0 - 7.8 \times 10^2 \text{ kg} \cdot \text{m/s} = -7.8 \times 10^2 \text{ kg} \cdot \text{m/s}$$

- c. What was the change in the tackle's momentum?

$$-7.8 \times 10^2 \text{ kg} \cdot \text{m/s}$$

- d. What was the tackle's original momentum?

$$7.8 \times 10^2 \text{ kg} \cdot \text{m/s}$$

- e. How fast was the tackle moving originally?

$$mv = 7.8 \times 10^2 \text{ kg} \cdot \text{m/s}, \text{ so}$$

$$m = \frac{7.8 \times 10^2 \text{ kg} \cdot \text{m/s}}{128 \text{ kg}} = 6.1 \text{ m/s}$$

17. A glass ball, ball A, of mass 5.0 g moves at a velocity of 20.0 cm/s. It collides with a second glass ball, ball B, of mass 10.0 g moving along the same line with a velocity of 10.0 cm/s. After the collision, ball A is still moving but with a velocity of 8.0 cm/s.

- a. What was the original momentum of ball A?

$$m_A v_A = (5.0 \times 10^{-3} \text{ kg})(0.200 \text{ m/s}) = 1.0 \times 10^{-3} \text{ kg} \cdot \text{m/s}$$

- b. What is the change in momentum of ball A?

$$m_A \Delta v_A = (5.0 \times 10^{-3} \text{ kg})(0.080 \text{ m/s} - 0.200 \text{ m/s}) = -6.0 \times 10^{-4} \text{ kg} \cdot \text{m/s}$$

- c. What is the change in momentum of ball B?

$$+6.0 \times 10^{-4} \text{ kg} \cdot \text{m/s}$$

## Chapter Review Problems

- d. What is the momentum of ball *B* after the collision?

$$\begin{aligned}mv_f &= mv_i + \Delta mv \\&= (10.0 \times 10^{-3} \text{ kg})(0.100 \text{ m/s}) \\&\quad + 6.0 \times 10^{-4} \text{ kg} \cdot \text{m/s} \\&= 1.60 \times 10^{-3} \text{ kg} \cdot \text{m/s}\end{aligned}$$

- e. What is ball *B*'s speed after the collision?

$$\begin{aligned}mv &= 1.60 \times 10^{-3} \text{ kg} \cdot \text{m/s}, \text{ so} \\v &= \frac{1.6 \times 10^{-3} \text{ kg} \cdot \text{m/s}}{10.0 \times 10^{-3} \text{ kg}} = 0.160 \text{ m/s} \\&= 16.0 \text{ cm/s}\end{aligned}$$

18. Before a collision, a 25-kg object is moving at +12 m/s. Find the impulse that acted on this object if after the collision it moves at

- a. +8.0 m/s.

$$\begin{aligned}F\Delta t &= m\Delta v = (25 \text{ kg})(8.0 \text{ m/s} - 12 \text{ m/s}) \\&= -1.0 \times 10^2 \text{ kg} \cdot \text{m/s}\end{aligned}$$

- b. -8.0 m/s.

$$\begin{aligned}F\Delta t &= m\Delta v = (25 \text{ kg})(-8.0 \text{ m/s} - 12 \text{ m/s}) \\&= -5.0 \times 10^2 \text{ kg} \cdot \text{m/s}.\end{aligned}$$

19. A 2575 kg van runs into the back of an 825-kg compact car at rest. They move off together at 8.5 m/s. Assuming no friction with the ground, find the initial speed of the van.

$$\begin{aligned}p_A + p_B &= p_A' + p_B' \\m_A v_A &= (m_A + m_B)v', \text{ so} \\v_A &= \frac{(m_A + m_B)v'}{m_A} \\&= \frac{(2575 \text{ kg} + 825 \text{ kg})(8.5 \text{ m/s})}{2575 \text{ kg}} \\&= 11 \text{ m/s}\end{aligned}$$

## Chapter Review Problems

20. A 15-g bullet is shot into a 5085 g wooden block standing on a frictionless surface. The block, with the bullet in it, acquires a velocity of 1.0 m/s. Calculate the velocity of the bullet before striking the block.

$$m_b v_b + m_w v_w = (m_b + m_w)v_i \text{ if } v_w = 0,$$

$$\begin{aligned}v_b &= \frac{(m_b + m_w)v}{m_b} \\&= \frac{(15 \text{ g} + 5085 \text{ g})(1.0 \text{ m/s})}{15 \text{ g}} \\&= 3.4 \times 10^2 \text{ m/s}\end{aligned}$$

21. A hockey puck, mass 0.115 kg, moving at 35.0 m/s, slides into an octopus thrown on the ice by a fan. The octopus has a mass of 0.265 kg. The puck and octopus slide off together. Find their velocity.

$$\begin{aligned}m_p v_p + m_o v_o &= (m_p + m_o)v', \text{ so} \\v' &= \frac{m_p v_p}{m_p + m_o} = \frac{(0.115 \text{ kg})(35 \text{ m/s})}{0.115 \text{ kg} + 0.265 \text{ kg}} \\&= 10.6 \text{ m/s}\end{aligned}$$

22. A 50-kg woman is riding on a 10-kg cart, and is moving east at 5.0 m/s. The woman jumps off the cart and hits the ground at 7.0 m/s eastward, relative to the ground. Calculate the velocity of the cart after she jumps off.

Let east be positive.

$$(m_w + m_c)v = m_w v_w' + m_c v_c' \text{ so}$$

$$\begin{aligned}v_c' &= \frac{[m_w + m_c]v - m_w v_w'}{m_c} \\&= \frac{[50 \text{ kg} + 10 \text{ kg}](5.0 \text{ m/s}) - (50 \text{ kg})(7.0 \text{ m/s})}{10 \text{ kg}} \\&= -5.0 \text{ m/s or } 5.0 \text{ m/s, west}\end{aligned}$$

## Chapter Review Problems

23. Two students on roller skates stand face-to-face, then push each other away. One student has a mass of 90 kg, the other 60 kg. Find the ratio of their velocities just after their hands lose contact. Which student has the greater speed?

$$\begin{aligned} P_A + P_B = 0 &= P_A' + P_B', \text{ so } m_A v_A' + m_B v_B' = 0, \text{ and } m_A v_A' = -m_B v_B' \\ v_A'/v_B' &= -m_B/m_A \\ &= -90/60 \\ &= -1.5 \end{aligned}$$

The negative sign shows that the velocities are in opposite directions. The student with the smaller mass has the larger velocity.

24. A car with mass 1245 kg moving at 29 m/s, strikes a 2175-kg car at rest. If the two cars stick together, with what speed do they move?

$$\begin{aligned} p_A + p_B &= p_A' + p_B' \\ m_A v_A + m_B v_B &= m_A v_A' + m_B v_B' = (m_A + m_B) v' \\ v' &= \frac{m_A v_A}{(m_A + m_B)} = \frac{(1245 \text{ kg})(29 \text{ m/s})}{(1245 \text{ kg} + 2175 \text{ kg})} = 10 \text{ m/s} \end{aligned}$$

25. A 92-kg fullback running at 5.0 m/s, attempts to dive across the goal line for a touchdown. Just as he reaches the goal line, he is met head-on in midair by two 75-kg linebackers, one moving at 2.0 m/s and the other at 4.0 m/s. If they all become entangled as one mass, with what velocity do they travel? Does the fullback score?

$$\begin{aligned} p_A + p_B + p_C &= p_A' + p_B' + p_C' \\ m_A v_A + m_B v_B + m_C v_C &= m_A v_A' + m_B v_B' + m_C v_C' = (m_A + m_B + m_C) v' \\ m_A v_A + m_B v_B + m_C v_C &= v' (m_A + m_B + m_C) \\ v' &= \frac{(m_A v_A + m_B v_B + m_C v_C)}{(m_A + m_B + m_C)} \\ &= \frac{(92 \text{ kg})(5.0 \text{ m/s}) + (75 \text{ kg})(-2.0 \text{ m/s}) + (75 \text{ kg})(-4.0 \text{ m/s})}{(92 \text{ kg} + 75 \text{ kg} + 75 \text{ kg})} \\ &= 0.041 \text{ m/s, over the goal line — touchdown!} \end{aligned}$$

26. A 5.00-g bullet is fired with a velocity of 100 m/s toward a 10.00-kg stationary solid block resting on a frictionless surface.

- a. What is the change in momentum of the bullet if it becomes embedded in the block?

$$\begin{aligned} m_b v_b &= m_b v' + m_w v' = (m_b + m_w) v', \text{ so } v' = \frac{m_b v_b}{m_b + m_w} = \frac{(5.00 \times 10^{-3} \text{ kg})(100 \text{ m/s})}{5.00 \times 10^{-3} \text{ kg} + 10.00 \text{ kg}} \\ &= 5.0 \times 10^{-2} \text{ m/s} \\ \Delta mv &= m_b(v' - v) = (5.00 \times 10^{-3} \text{ kg})(5.0 \times 10^{-2} \text{ m/s} - 100 \text{ m/s}) = -0.500 \text{ kg} \cdot \text{m/s} \end{aligned}$$

- b. What is the change in momentum of the bullet if it ricochets in the opposite direction with a speed of 99 m/s — almost the same speed as it had originally?

$$\Delta mv = m_b(v' - v) = (5.00 \times 10^{-3} \text{ kg})(-99 \text{ m/s} - 100 \text{ m/s}) = -0.995 \text{ kg} \cdot \text{m/s}$$



27. A 0.200-kg plastic ball moves with a velocity of 0.30 m/s. It collides with a second plastic ball of mass 0.100 kg moving along the same line at a velocity of 0.10 m/s. After the collision, the velocity of the 0.100-kg ball is 0.26 m/s. What is the new velocity of the first ball?

$$m_A v_A + m_B v_B = m_A v_A' + m_B v_B', \text{ so}$$

$$\begin{aligned} v_A' &= \frac{m_A v_A + m_B v_B - m_B v_B'}{m_A} \\ &= \frac{(0.200 \text{ kg})(0.30 \text{ m/s}) + (0.100 \text{ kg})(0.10 \text{ m/s}) - (0.100 \text{ kg})(0.26 \text{ m/s})}{0.200 \text{ kg}} \\ &= 0.22 \text{ m/s in the original direction.} \end{aligned}$$

28. Figure 9-18 shows a brick weighing 24.5 N being released from rest on a 1.00 m, frictionless plane inclined at an angle of  $30.0^\circ$ . The brick slides down the incline and strikes a second brick weighing 36.8 N.

- a. Calculate the speed of the brick at the bottom of the incline.

$$F_{\parallel} = F_w \sin \theta = (24.5 \text{ N})(\sin 30.0^\circ) = 12.3 \text{ N}$$

$$F = ma, \text{ and } m = \frac{W}{g}, \text{ so } a = \frac{F}{m} = \frac{Fg}{W} = \frac{F_{\parallel} g}{F_w} = \frac{(12.3 \text{ N})(9.80 \text{ m/s}^2)}{24.5 \text{ N}} = 4.9 \text{ m/s}^2$$

$$v^2 = 2ad = 2(4.9 \text{ m/s}^2)(1.00 \text{ m}), \text{ so } v = 3.1 \text{ m/s}$$

- b. If the two bricks stick together, with what initial speed will they move along the table?

$$m_A v_A = (m_A + m_B) v', \text{ so } v' = \frac{m_A v_A}{m_A + m_B} = \frac{(2.50 \text{ kg})(3.1 \text{ m/s})}{2.50 \text{ kg} + 3.76 \text{ kg}} = 1.24 \text{ m/s}$$

- c. If the force of friction acting on the two bricks is 5.0 N, how much time will elapse before the bricks come to rest?

$$F \Delta t = m \Delta v, \text{ so } \Delta t = \frac{m \Delta v}{F} = \frac{(2.50 \text{ kg} + 3.76 \text{ kg})(1.24 \text{ m/s})}{5.0 \text{ N}} = 1.6 \text{ s}$$

- d. How far will the two bricks slide before coming to rest?

$$d = \frac{1}{2}(v_1 + v)t = \frac{1}{2}(1.24 \text{ m/s} + 0)(1.6 \text{ s}) = 0.99 \text{ m}$$

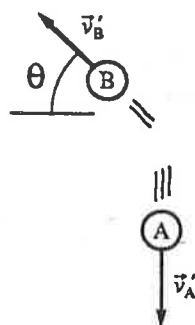
# Chapter Review Problems

29. Ball A, rolling west at 3.0 m/s, has a mass of 1.0 kg. Ball B has a mass of 2.0 kg and is stationary. After colliding with ball B, ball A moves south at 2.0 m/s. Calculate the momentum and velocity of ball B after the collision.

Before



After



Horizontal:  $m_A v_A = m_B v_B$ , so

$$m_B v_B = (1.0 \text{ kg})(3.0 \text{ m/s}) = 3.0 \text{ kg} \cdot \text{m/s}$$

Vertical:  $0 = m_A v_A' + m_B v_B'$ , so

$$m_B v_B' = -(1.0 \text{ kg})(2.0 \text{ m/s}) = -2.0 \text{ kg} \cdot \text{m/s}$$

The vector sum is;

$$mv = \sqrt{(3.0 \text{ kg} \cdot \text{m/s})^2 + (-2.0 \text{ kg} \cdot \text{m/s})^2} \\ = 3.6 \text{ kg} \cdot \text{m/s} \text{ and}$$

$$\tan \theta = \frac{2.0 \text{ kg} \cdot \text{m/s}}{3.0 \text{ kg} \cdot \text{m/s}}, \text{ so } \theta = 34^\circ.$$

Therefore,  $m_B v_B' = 3.6 \text{ kg} \cdot \text{m/s}$  at  $34^\circ$  N of W

$$v = \frac{3.6 \text{ kg} \cdot \text{m/s}}{2.0 \text{ kg}} = 1.8 \text{ m/s} \text{ at } 34^\circ \text{ N of W}$$

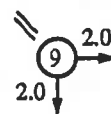
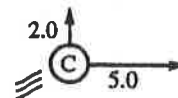
30. A cue ball, moving with 7.0 N·s of momentum strikes the 9-ball at rest. The 9-ball moves off with 2.0 N·s in the original direction of the cue ball and 2.0 N·s perpendicular to that direction. What is the momentum of the cue ball after the collision?

# Chapter Review Problems

Before



After



Horizontal:  $m_C v_C = m_C v_C' + m_9 v_9'$ , so

$$7.0 \text{ N} \cdot \text{s} = m_C v_C' + 2.0 \text{ N} \cdot \text{s}, \text{ so}$$

$$m_C v_C' = 5.0 \text{ N} \cdot \text{s}$$

Vertical:  $0 = m_C v_C' + m_9 v_9'$ , so

$$m_C v_C' = -m_9 v_9' = -2.0 \text{ N} \cdot \text{s}$$

The vector sum is;

$$\sqrt{(5.0 \text{ N} \cdot \text{s})^2 + (2.0 \text{ N} \cdot \text{s})^2} = 5.4 \text{ N} \cdot \text{s} \text{ and}$$

$$\tan \theta = \frac{2.0 \text{ N} \cdot \text{s}}{5.0 \text{ N} \cdot \text{s}}, \text{ so } \theta = 22^\circ.$$

Therefore  $m_C v_C' = 5.4 \text{ N} \cdot \text{s}$  at  $22^\circ$  from original direction.

31. A 7600-kg space probe is traveling through space at 120 m/s. Mission control determines that a change in course of  $30.0^\circ$  is necessary and, by electronic communication, instructs the probe to fire rockets perpendicular to its direction of motion. If the escaping gas leaves the craft's rockets at an average speed of 3200 m/s, what mass of gas should be expelled?

$$\tan 30.0^\circ = \frac{m \Delta v}{m_p \Delta v_p}$$

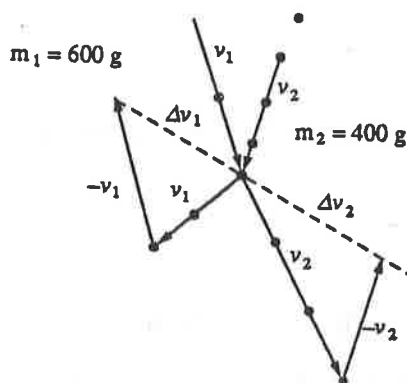
$$m \Delta v = m_p \Delta v_p \tan 30.0^\circ \\ = (7600 \text{ kg})(120 \text{ m/s})(\tan 30.0^\circ) \\ = 5.3 \times 10^5 \text{ kg} \cdot \text{m/s}$$

$$m_p \Delta v_p = m_g \Delta v_g = m \Delta v$$

$$m_g = \frac{m \Delta v}{\Delta v_g} = \frac{(5.3 \times 10^5 \text{ kg} \cdot \text{m/s})}{(3.2 \times 10^3 \text{ m/s})} \\ = 170 \text{ kg}$$



32. Figure 9-19, which is drawn to scale, shows two balls during an elastic collision. The balls enter from the left of the page, collide, and bounce away. The heavier ball at the bottom of the diagram has a mass of 600 g, while the ball on the top has a mass of 400 g. Using a vector diagram, determine if momentum is conserved in this collision. *Hint: Remember that the two masses are not equal.* Try to account for any discrepancy found in the total momentum before and after the collision.



Dotted lines show that the changes of momentum for each ball are equal and opposite:  $\Delta(m_1 v_1) = \Delta(m_2 v_2)$ . Since the masses are in a 3:2 ratio, a 2:3 ratio of velocity changes will compensate.

33. The head of a 1.0-kg hammer, moving at 3.6 m/s, strikes a nail and drives it into hardwood.
- The head stays in contact 2.0 ms and rebounds with negligible velocity. What is the average force exerted on the nail?

The force on the nail is opposite the force on the hammer, so

$$\begin{aligned} F_n &= -F_h = -\frac{m_h \Delta v_h}{\Delta t} \\ &= -\frac{(1.0 \text{ kg})(0 - 3.6 \text{ m/s})}{2.0 \times 10^{-3} \text{ s}} \\ &= 1.8 \times 10^3 \text{ N} \end{aligned}$$

- When the same hammer hits a springy nail, it rebounds with the same speed, 3.6 m/s. The contact time is the same. What force is exerted this time?

$$\begin{aligned} F_n &= -F_h = -\frac{m_h \Delta v_h}{\Delta t} \\ &= -\frac{(1.0 \text{ kg})(-3.6 \text{ m/s} - 3.6 \text{ m/s})}{2.0 \times 10^{-3} \text{ s}} \\ &= 3.6 \times 10^3 \text{ N} \end{aligned}$$

### Supplemental Problems (Appendix B)

- Jim strikes a 0.058-kg golf ball with a force of 272 N and gives it a velocity of 62.0 m/s. How long was the club in contact with the ball?

$$\Delta t = \frac{m \Delta v}{F} = \frac{(0.058 \text{ kg})(62.0 \text{ m/s})}{272 \text{ N}} = 0.013 \text{ s}$$

- A force of 186 N acts on a 7.3-kg bowling ball for 0.40 s.

- What is the bowling ball's change in momentum?

$$\Delta p = F \Delta t = (186 \text{ N})(0.40 \text{ s}) = 74 \text{ N} \cdot \text{s}$$

- What is its change in velocity?

$$\Delta v = \frac{\Delta p}{M} = \frac{74 \text{ N} \cdot \text{s}}{7.3 \text{ kg}} = 1.0 \times 10^1 \text{ m/s}$$

- A 5500-kg freight truck accelerates from 4.2 m/s to 7.8 m/s in 15.0 s by applying a constant force.

- What change in momentum occurs?

$$\begin{aligned} \Delta p &= m \Delta v = (5500 \text{ kg})(7.8 \text{ m/s} - 4.2 \text{ m/s}) \\ &= 2.0 \times 10^4 \text{ kg} \cdot \text{m/s} \end{aligned}$$

- How large of a force is exerted?

$$\begin{aligned} F &= \frac{\Delta p}{\Delta t} = \frac{2.0 \times 10^4 \text{ kg} \cdot \text{m/s}}{15.0 \text{ s}} \\ &= 1.3 \times 10^3 \text{ N} \end{aligned}$$

## Supplemental Problems



4. In running a ballistics test at the police department, Officer Spears fires a 6.0-g bullet at 350 m/s into a container that stops it in 0.30 m. What average force stops the bullet?

$$\Delta p = m\Delta v = (0.0060 \text{ kg})(-350 \text{ m/s}) = -2.1 \text{ kg}\cdot\text{m/s}$$

$$t = d \left[ \frac{2}{v_f + v_i} \right] = (0.30 \text{ m}) \left[ \frac{2}{0 \text{ m/s} + 350 \text{ m/s}} \right] = 1.7 \times 10^{-3} \text{ s}$$

$$F = \frac{\Delta p}{\Delta t} = \frac{-2.1 \text{ kg}\cdot\text{m/s}}{1.7 \times 10^{-3} \text{ s}} = -1.2 \times 10^3 \text{ N}$$

5. A 0.24-kg volleyball approaches Jennifer with a velocity of 3.8 m/s. Jennifer bumps the ball giving it a velocity of -2.4 m/s. What average force did she apply if the interaction time between her hands and the ball is 0.025 s?

$$F = \frac{m\Delta v}{\Delta t} = \frac{(0.24 \text{ kg})(-2.4 \text{ m/s} - 3.8 \text{ m/s})}{0.025 \text{ s}} = -6.0 \times 10^1 \text{ N}$$

6. A 0.145-kg baseball is pitched at 42 m/s. The batter hits it horizontally to the pitcher at 58 m/s.

- a. Find the change in momentum of the ball.

Take the direction of the pitch to be positive direction

$$\Delta p = mv_f - mv_i = m(v_f - v_i) = (0.145 \text{ kg})(-58 \text{ m/s} - (+42 \text{ m/s})) = -14.5 \text{ kg}\cdot\text{m/s}$$

- b. If the ball and bat were in contact  $4.6 \times 10^{-4}$  s, what would be the average force while they touched?

$$F\Delta t = \Delta p,$$

$$F = \Delta p / \Delta t = (-14.5 \text{ kg}\cdot\text{m/s}) / (4.6 \times 10^{-4} \text{ s}) = -3.2 \times 10^4 \text{ N}$$

7. A 550-kg car traveling at 24.0 m/s collides head-on with a 680-kg pick-up truck. Both vehicles come to a complete stop upon impact.

- a. What is the momentum of the car before collision?

$$P = mv = (550 \text{ kg})(24.0 \text{ m/s}) = 1.32 \times 10^4 \text{ kg}\cdot\text{m/s}$$

- b. What is the change in the car's momentum?

$$-1.32 \times 10^4 \text{ kg}\cdot\text{m/s}, \text{ since car stops on impact}$$

- c. What is the change in the truck's momentum?

$$+1.32 \times 10^4 \text{ kg}\cdot\text{m/s}, \text{ by conservation of momentum}$$

- d. What is the velocity of the truck before collision?

$$v = \frac{P}{M} = \frac{-1.32 \times 10^4 \text{ kg}\cdot\text{m/s}}{680 \text{ kg}} = -19.4 \text{ m/s}$$